found to have sustained little damage and was easily repaired. I was unable to take readings until the 6th of October, unfortunately the clockwork of the barograph having got wet, and sand having found its way into the works of the anemometer register, the whole thing being wrecked. I was able to construct a makeshift from parts on hand * * *.

To illustrate the force of the water from the swell: A small boat of 14 feet * * * was hauled up in front of my residence situated on Front Street. This boat was carried over the abutment, over a 4 ft. 6 in. gate, round the yard, knocking down an outbuilding and finally coming to anchor by my carriage house. The sea rushed through my residence as if a river, at times being knee deep. Sand from the beach in the yard was above one's knees. The island even now is a perfect wreck and will take a large amount of money and time to put in any state of order * * *.

Date	Hour	Barometer	Wind	Sky	Sea
Sept. 15	------------	29.910	NE., 10 m.p.h.	Clear	
Sept. 16	8 a. m.	29.751	NW., 18	Cloudy	
	10:20 a. m.	29.630	NW., 36	Cloudy	Heavy swell.
	1:00 p. m.	29.265	NW., 100	Cloudy	Very heavy swell and intensity of storm increasing.

Measured precipitation 10 inches and rain still falling. Heavy swell carried rain gage some distance inland.

A. ÅNGSTRÖM ON "RADIATION AND CLIMATE"

551.590.2 : 551.524

By H. H. KIMBALL

[A review of *Geografiska Annaler*, 1925, H. 1, och. 2]

The paper deals principally with the heating effect of solar radiation received by the earth. It is based upon measurements made at or near Stockholm, Sweden, of the total radiation received on a horizontal surface directly from the sun and diffusely from the sky (Q), and the diffuse sky radiation alone (D); the net loss of heat due to the difference between the long-wave outward radiation from the surface of the earth and radiation of corresponding wave length to the earth from the atmosphere (R); the evaporation from the surface of the earth, and the reflection from snow surfaces.

From measurements of Q made since June, 1922, and records of the duration of sunshine, n, since 1908, the relation

$$Q_s = Q_o\ (0.25 + 0.75\ S) \qquad (1)$$

has been determined, where for a given day or a given month, Q_s is the average radiation receipt, Q_o the radiation that would have been received with a cloudless sky of average clearness, and $S = \frac{n}{N}$, where n is the number of hours of sunshine recorded by a modified Jordan photographic recorder, and N is the possible number of hours of sunshine.[1]

TABLE 1

	Monthly evaporation, mm.	Heat of evaporation	Reflection from snow surface	Outgoing radiation	3+4+5	Radiation income			9−6
						Sun	D (sky)	Q (total)	
January	7	420	420	3,570	4,410	180	670	850	−3,560
February	8	480	1,210	3,600	5,290	787	1,723	2,510	−2,780
March	15	900	2,030	3,900	6,830	2,640	1,870	4,510	−2,320
April	28	1,680	1,250	4,320	7,250	5,600	3,250	8,850	+1,600
May	47	2,820	-------	4,950	7,770	9,420	3,035	12,455	+4,685
June	67	4,020	-------	4,900	8,920	9,350	2,820	12,170	+3,250
July	73	4,380	-------	4,470	8,850	8,520	3,040	11,560	+2,710
August	61	3,660	-------	4,050	7,710	5,900	3,250	9,150	+1,440
September	40	2,400	-------	4,110	6,510	3,640	2,750	6,390	−120
October	23	1,380	120	3,510	5,010	1,166	1,800	2,970	−2,040
November	13	780	200	3,420	4,400	226	1,000	1,230	−3,170
December	8	480	270	2,940	3,690	47	690	740	−2,950
1	2	3	4	5	.6	7	8	9	10

The values in columns 3 to 10, inclusive, are expressed in gram-calories per square centimeter of horizontal surface.

The measured values of (Q) and (D) for Stockholm have been smoothed by equation (1), and the monthly mean results are reproduced here in Table 1 under "Radiation income."

In the same way it is shown that the average outgoing radiation R_m may be determined with reasonable accuracy from the equation

$$R_m = R_o\ (0.25 + 0.75S) \qquad (2)$$

where R_o is the loss with a clear sky and S has the same significance as in equation (1).

The monthly mean values of R_m for Stockholm are given in Table 1 under the heading "Outgoing radiation."

The author shows that Q_o, Q_s ($=Q_m$ for monthly values), and R_m may be represented by Fourier series as in Table 2.

TABLE 2.—*Values of constants in formula*

$$A + a_1 \sin(\phi + x) + a_2 \sin(\phi_2 + 2x) + a_3 (\phi_3 + \sin 3x)$$

	A	a_1	ϕ_1	a_2	ϕ_2	a_3	ϕ_3
			°		°		°
Q_o	10,780	9,050	295.1	295	164.5	440	154
Q_m	6,100	6,130	296.5	590	170.2	440	109
R_m	3,980	780	305.2	90	206.5	-------	-------
Q_m-R_m	2,120	5,380	295.5	520	164.3	-------	-------
W	−270	3,740	295.2	800	185.2	-------	-------

The values of Q, R, and W are given in gr. cal. per cm.^{2}; $x=0°$ and $360°$ on January 15.

The quantity $Q_m - R_m$ is designated by the author the "heat effective net radiation." Its monthly mean values may be found by subtracting values in column 5, Table 1, from values in column 9. The resulting values of $Q_m - R_m$ may be represented by a series, the constants of which are given in Table 2.

If we deduct from $Q_m - R_m$ the heat lost through evaporation from the surface of the earth and through reflection from the snow-covered surface, the monthly means of which are given in columns 3 and 4, Table 1, we obtain the "temperature effective energy," or W, the monthly mean values of which are given in the last column of Table 1. The constants of the Fourier series for W also are given in Table 2.

The author's discussion of Table 2 follows:

The table is instructive in many respects. It shows that the amplitude[2] of the second term, the whole-year term, as regards the total incoming radiation from sun and sky under the condition

[1] The equation obtained by the reviewer from monthly mean values of Q recorded by the Callendar recording pyrheliometer and of n recorded by the Marvin sunshine recorder is $Q_s = Q_o\ (0.22 + 0.78S)$. See Monthly Weather Review, 47:780, Figure 9, November, 1919.

[2] Amplitude here and in the following is equal to a_1, a_2, a_3 * * * and consequently equal to half the difference between maximum and minimum values.

of constantly clear weather, reaches a value of 9,050 gram calories, the monthly average being almost 10,800 calories. Through the influence of cloudiness the amplitude of the second term is reduced to 6,130 calories and the monthly mean value to 6,100 calories. When energy and not illumination is considered, we find these values to decrease to respectively 5,380 and 2,120 on account of losses of heat through the outgoing dark radiation. But even these values represent extremes which are never reached. If we take into account also the heat-spending effect of evaporation, we find the yearly amplitude reduced to 3,740 calories and the monthly mean to a value which is slightly negative.

The phase angle of the whole-year term keeps, as regards the different energy quantities considered, a remarkably unchanged value, namely, 295.5°, the differences between this value in the various cases falling below the probable error, which is about ±1.5°. *This means, as we have counted the time from January 15th as zero, that the maximum of the annual harmonic variation (at June 21) almost exactly coincides with the summer solstice, the minimum December 22 with the winter solstice.* This fact, brought out by observations and registrations, seems well worth emphasizing.

The third term in the development is the mathematical expression of the fact that the radiation income is not symmetrical with respect to the solstices, but that on account of the variations in the transmission power of the atmosphere, it is larger in spring than in autumn. The semiannual variation has a maximum in the end of May or during the first 10 days of June, another maximum in the beginning of December. Its minimum occurs in the end of August and in the beginning of March.

Passing now to the principal object of the paper, namely, the relation between radiation and temperature, the author finds the monthly mean temperature of Stockholm expressed in degrees centigrade, to be as follows:

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
−3.1	−1.9	−0.7	3.8	9.0	13.9	16.8	15.2	11.0	6.4	1.7	−0.9	5.9

From these the following series is obtained:

$$\theta = 5.9 + 9.7 \sin(262.2^\circ + x) + 1.0 \sin(90^\circ + 2x) + 0.2 \sin(288.5^\circ + 3x) \tag{3}$$

From the second term it is seen that the maximum and minimum phases occur 33 days later than the maximum and minimum of the *temperature effective energy, W.*

Certain fundamental assumptions are made as to the relation between radiation and temperature, as follows:

I. To a given constant transfer of energy, W, corresponds at a certain locality a certain final temperature T_w, to which the temperature approaches as near as we wish, provided that we wait a sufficient time.

II. The velocity with which the temperature θ changes is in every time moment proportional to the differences $(T_w - \theta)$. We consequently have

$$\frac{d\theta}{dt} = c(T_w - \theta) \tag{4}$$

where t is the time and c is a constant.

III. The change in T_w is related to a given change in W through a linear function

$$dT_w = k\,dW$$

which gives

$$T_w = T_o + kW \tag{5}$$

where T_o is the temperature which corresponds to $W=0$, and k is a constant.

The author states that these three constants, c, k, and T_o are characteristic of the temperature climate of a place. It is probable that $k = dT_w/dW$ varies but little with locality. On the other hand, the value of

$$c = \frac{d\theta/dt}{T_w - \theta}$$

varies with place depending upon the distribution of land and sea, and the character of the ground surface. The value of c gives a clearly defined measure of the degree of continentality of a place. The greater the value of c the more quickly the temperature reaches the final state, T_w, and the smaller the difference in phase between variations in energy income and in temperature.

We may solve for T_o and k from the equation $\theta = T_w[d\theta/dt = 0]$, and equation (5).

For Stockholm we have at the summer maximum of temperature and the winter minimum, respectively

$$\begin{array}{rl} 16.9^\circ = & T_o + 2{,}700k \\ -3.1^\circ = & T_o - 3{,}250k \\ \hline 20.0^\circ = & \quad\quad 5{,}950k \end{array} \quad k = 0.00336, \text{ and } T_o = 7^\circ.8$$

For variations in the value of θ with time the author gives the equation

$$\theta = T_m + M \sin \frac{2\pi t}{p} \tag{6}$$

where T_m = the annual mean temperature, M = the temperature amplitude, t = time, and p = time of a complete cycle. From the above

$$\frac{d\theta}{dt} = M \frac{2\pi}{p} \cos \frac{2\pi t}{p}$$

By substitution

$$\begin{aligned} W &= \frac{T_m - T_o}{k} + M\left(1/k \sin \frac{2\pi t}{p} + \frac{2\pi}{kcp} \cos \frac{2\pi t}{p}\right) \\ &= \frac{T_m - T_o}{k} + M\gamma \sin\left(\frac{2\pi t}{p} + \phi\right) \end{aligned} \tag{7}$$

when $\tan \phi = \frac{2\pi}{pc}$ and $\gamma = \frac{\sec \phi}{k}$.

For Stockholm ϕ = difference in phase between W and $\theta = 33^\circ$, and γ = factor to reduce temperature amplitude to *temperature effective energy* amplitude, $= 3740/9.7 = 386$. Therefore, $c = 0.80$ and $k = 0.0031$, instead of 0.00336, as computed from equation (5).

The value of c varies inversely with the value of $\tan \phi$, as is illustrated by the values in Table 3, which gives values of c corresponding to different values of ϕ, and temperature amplitudes corresponding to the computed values of c and different amplitudes of *temperature effective energy.*

TABLE 3

$k=0.0031$								
ϕ	days	c	Energy amplitude (gram calories per month)					
			1,000	2,000	3,740	6,000	8,000	
0°	0	--------	3°.1	6°.2	11°.5	18°.5	24°.8	Temperature amplitude.
15°	15	1.93	3°.0	6°.0	11°.2	18°.0	24°.0	
33°	30.5	0.80	2°.6	5°.2	9°.7	15°.6	20°.8	
45°	46	0.52	2°.2	4°.4	8°.2	13°.2	17°.6	
60°	61	0.30	1°.6	3°.1	5°.8	9°.3	12°.4	
75°	77	0.14	0°.8	1°.6	3°.0	4°.8	6°.4	

The table shows that a decrease in ϕ below 33° does not greatly increase the temperature amplitude—from 9.7° to 11.5° at Stockholm, for instance—while an increase in ϕ greatly reduces the temperature amplitude—

at Stockholm, from 9.7° to 3.0°. Therefore, to account for temperature amplitudes of 20° or more, which are common in continental climates in temperate zones, there must be increased amplitude in *temperature effective energy*. Table 1 indicates that this may be brought about through a decrease in cloudiness and in surface evaporation, both of which conditions commonly are characteristic of continental climates.

Under "Applications" the effects of variations in the average amount and the annual distribution of cloudiness are discussed. Since such variation would affect the evaporation and also the reflection from snow surfaces, the equation for $Q_m - R_m$, the *heat* effective net radiation is considered in connection with the equation for θ. In this case $d\theta/dt = c(T_w - \theta)$ as before; but $T_w = T_o + kQ$.

From the values of θ and Q at times of maximum and minimum values of θ the values of k and γ are found to be 0.0022 and 555, respectively.

The annual average percentage of possible sunshine for Stockholm is 39. Assuming this to be uniform throughout the year we obtain a Fourier series for θ_c which gives an annual temperature 1.2° lower and an amplitude 1.1° less than the series for θ. Assuming the skies to be cloudless throughout the year the series for θ_o is obtained, which gives an annual temperature 1.8° higher and an amplitude 6.3° greater than the observed.

The influence of variations in the value of the solar constant with the 11-year sunspot period is also considered, and it is shown that a solar-constant variation of 3.0 per cent over this period would cause the temperature to be 0.4° higher at sunspot maximum than at sunspot minimum, provided the variations in solar intensity did not cause variations in atmospheric transmissibility. As a matter of fact there are indications of increased cloudiness at sunspot maximum, especially at the cirrus level, so that actually the mean temperatures are a little lower at maximum than at minimum of solar spottedness. For this and other reasons the effect of solar variability upon earth temperatures is not clearly apparent.

It is pointed out that considerations quite similar to those here applied to annual variations of radiation and temperature, are applicable to semiannual and daily variations, with, however, a probable change in the value of the constants.

The results obtained seem to the reviewer to indicate that changes taking place within the atmosphere are capable of producing greater temperature variations, and therefore greater weather changes, than can be brought about by solar constant variations of the order of magnitude that are indicated by researches that have been published up to this time.

BROADCASTING WEATHER MAPS BY RADIO

551.509

By B. FRANCIS DASHIELL

[Forecast Division, Weather Bureau, Washington, D. C.]

It is a long step from the first broadcasting of a brief coded weather bulletin issued by the United States Weather Bureau from the Naval radio station NAA, at Arlington, Va., on July 13, 1913, to the transmission, through the same station, of the first complete radio weather-map picture on August 18, 1926.

Arlington's weather bulletins are familiar to nearly all radio operators and navigators. It was most fitting, therefore, that the opening of this new era in the dissemination of weather information should be done through the same station that made the original weather broadcasts in 1913.

The possibility of using radio for transmitting weather maps by the system to be described in this note is based on the fact that C. Francis Jenkins, its inventor, had already transmitted pictures, writing, etc., by his "Television" method. This method appeared to hold great possibilities for the Weather Bureau. If pictures could be sent, why not weather maps? Acting on this idea, E. B. Calvert, chief of the Forecast Division of the Bureau, suggested a conference, at which Mr. Jenkins's invention was inspected and its possibilities as a transmitter of weather maps discussed. The ultimate result of this conference was that, on August 18, 1926, the Navy Department cooperating, a special weather map was taken to the Arlington Radio Station, whence it was radioed to the Weather Bureau with remarkably good reproduction. (See Figure 1.)

In order that extensive tests might be conducted, the Navy Department not only generously loaned the services of its most powerful transmitter at Arlington, operating on 8,300 meters and using from 20 to 40 kilowatts, but it also conducted reception tests aboard U. S. S. *Kittery* and U. S. S. *Trenton* at sea.

The first transmission, on August 18th, was so satisfactory that on August 23d the Chief of Bureau invited members of the press and interested Government officials to a demonstration. Naval officials commented on the value that such a device would be to navigation, and the press of the country carried descriptions of the apparatus.

The tests of radio vision apparatus for broadcasting daily weather maps to ships at sea, as well as to others interested, though still in the experimental stage, show that such broadcasting is sound in theory and has considerable promise of being entirely practicable. But little is known as to the effectiveness of operation over considerable distances and during unfavorable conditions, such as static, wave-length interference, fading, the rolling of vessels, etc. These potential sources of trouble are being gradually investigated. Reception by the *Trenton* and *Kittery* was not entirely satisfactory, due to static and the rolling of the vessels, but maps were received by the *Kittery* as far south as Guantanamo Bay, Cuba. It is hoped that more tests can be conducted under seagoing conditions as improvements in radio and in the mechanical part of the transmission are made from time to time.

The Weather Bureau's experience, as well as that of the observers aboard the naval vessels, is that a map can be received through much static without destroying its value. All static impulses passing through the radio set are recorded as marks of various lengths on the map. This static would seriously interfere with ear reception of coded bulletins and, in many cases, may prevent the obtaining of sufficient data to prepare a map at sea. One map was received at the Weather Bureau during a heavy thunderstorm but the isobars and other data were quite legible. Incidentally, the recording of static impulses by this machine show some interesting actions of the electric waves that are propagated by lightning discharges.

In order to conduct still further tests under other conditions a 45-meter short-wave transmitter of the Jenkins Laboratories at Washington is also used. A